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MARKED SUMMER AIR-MASS DISPLACEMENTS IN CALIFORNIA AND THEIR EFFECTS ON WEATHER

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[Weather Bureau office, San Francisco, Calif., December 1933]

Because of California's shape and size, the modifying effect of topography on its weather presents many interesting and seemingly anomalous phenomena. Not the least of these is a sea breeze that penetrates more than 100 miles from the sea. The sea and land breezes along most of the California coast in the spring, summer, and fall, are not sea and land breezes in the ususal interpretation of the term, namely, a landward flow of air in the daytime and a seaward flow during the night, respectively. The usual occurrence in the San Francisco Bay region is a flow of air from the land of several days' duration and then a reversal of movement with air from the ocean flowing onto the land. The latter is much better defined and always of longer duration.

California has mountain ranges extending north and south along its east and west sides. These together with the east-west connecting chains at the northern and near the southern end enclose large interior valleys, the Sacramento and San Joaquin. There is little level land between the Coast Range and the Pacific Ocean, but several small valleys are found in the Coast Range. The Santa Clara Valley is really an extension of San Francisco Bay. To the southward is the San Benito Valley. Nearly parallel to these, but somewhat to the westward, is the Salinas Valley which is open to the Pacific through Monterey Bay. Several small valleys extend northward from San Pablo Bay, the Napa and Petaluma Valleys among them. These features are all indicated on the accompanying map (frontispiece).

The normal summer condition is for marine air to be the dominant factor in the littoral sections with dry, hot air over the interior valleys. As long as this condition prevails day to day weather changes are inconsequential.

Topography is such that lower layers of air from the ocean have no means of ingress into the central portion of the interior valley except through the Golen Gate and over the lower coastal hills to the northward and southward of the Gate, thence through San Pablo and Suisun Bays. The prevailing wind of summer in the bay region is from the west; and the movement is so steady that it is locally referred to as the "summer trade wind."

On occasion in the late spring, summer, and early fall the general pressure distribution is such that the air movement is from the Plateau region (the land breeze of our discussion) and of such force as to divert or obstruct the wind from the ocean. The flow of this air from the Plateau over the Sierra Nevada and Siskiyou Mountains is essentially a chinook wind, hot and desiccating. The highest temperatures in the coastal regions occur while these conditions obtain. Upon the cessation of the air flow from the Plateau, the "summer trade winds" (the sea breeze in this discourse) set in again; and the marine air from the Pacific flows into the Sacramento and San Joaquin Valleys as well as into many of the smaller coastal valleys.

The marine air masses of the Pacific can be divided into two classes. The one most common in the summer is never deep and has its origin on the east side of the subsiding Pacific high. The water vapor of this class is acquired through evaporation from the ocean water surface. Turbulence tends towards homogenous water vapor distribution in the shallow layer as the air moves inland. At times this air penetrates to the extremities of the valleys. At other times the penetration is confined to the delta region of the San Joaquin and Sacramento Rivers. The other class of marine air is of cyclonic origin, of varying depth, and not homogenous. Its depth often exceeds that of the coastal range and at times is greater than the altitude of the Sierra Nevada. In the discussion which follows, the first invasion of marine air was of the first class. It was followed shortly by air associated with cyclonic activity.

The sequence of changes from the landward to the seaward wind or vice versa can best be shown by taking a typical example; and of the many cases studied that of August 12 to 16, 1933, seems best suited.

The 8 a.m. weather map of August 12 shows a Pacific HIGH in its normal southwest to northeast position with a rather weak extension into Washington, Oregon, and the northern Plateau region; the whole in the form of a large inverted "L". Between the legs of the L is the usual summer LOW in the southwest with a trough extending north-northwestward over California. By the 13th the trough has worked its way northward from the southwest thermal LOW to the California-Oregon State line. On this date the weather situation in California can best be described as stagnant. There is no well-defined air movement, either at the surface or aloft. Sacramento reported the highest August temperature of record. Grizzly Peak Lookout located in the Berkeley Hills, 3 miles from the bay shore, at an elevation of 1,760 feet (a.m.s.l.) reported a maximum of 104° F. The maximum temperature at the cooperative station on the University of California campus, Berkeley (299 feet above sea level and about 1 mile due west of Grizzly Peak), was 74° F. At San Francisco the maximum temperature was 71° F., and at the Oakland Airport on the east side of the bay 82° F. was the highest for the day.

While temperature is not an index of composition of air, such large differences in such short distances invite an analysis of the air masses here involved. Since the water vapor is the only constituent of the atmosphere that is

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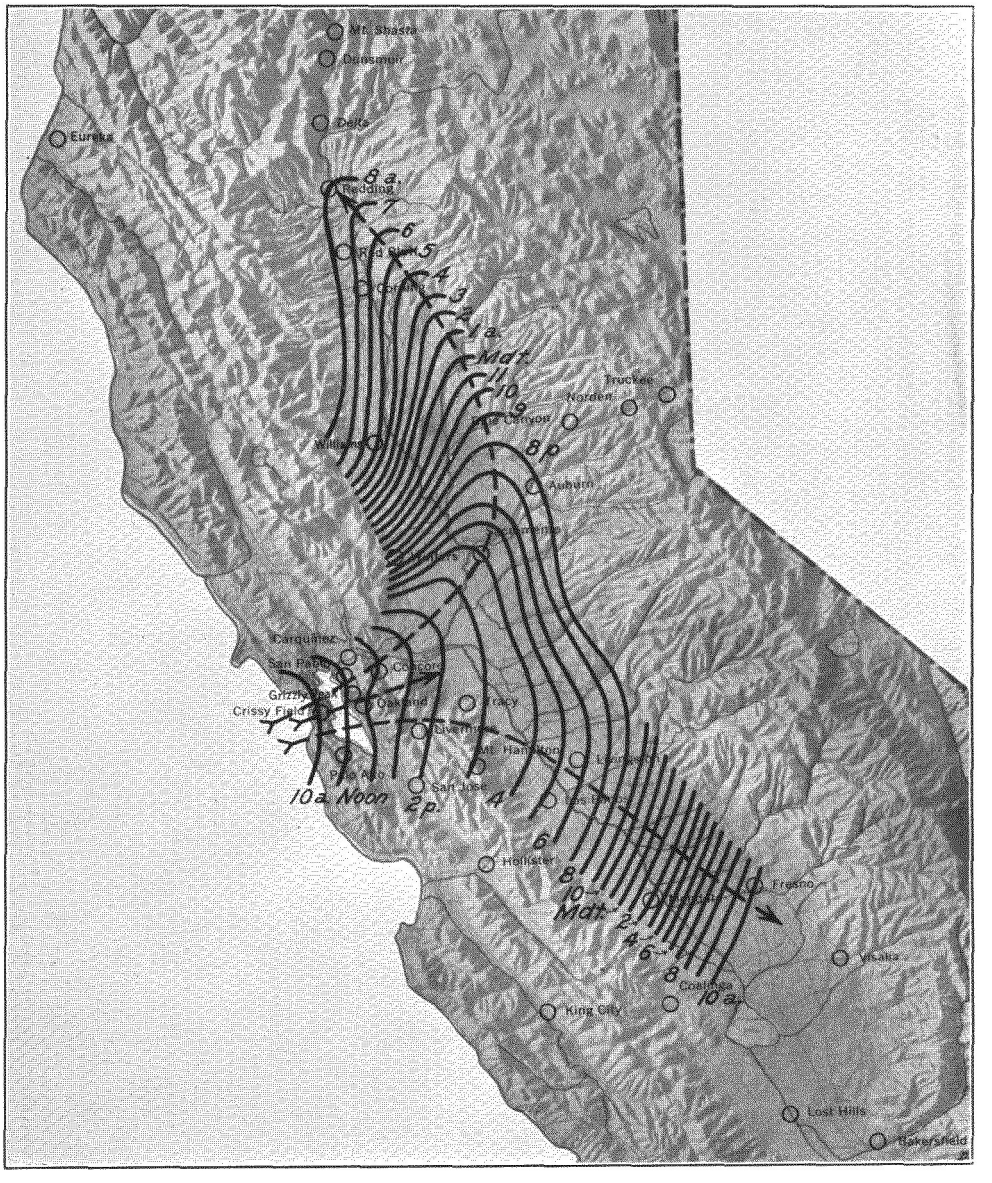

FRONTISPIECE.—California, showing relief features, path of the marine air inland, and hourly positions of the advancing front.

Station	Elevation a.m.s.l.	Air path distance from ocean	Station	Elevation a.m.s.l.	Air path distance from ocean
	Feet	*Miles*		*Feet*	*Miles*
San Francisco	238	5	Fresno	327	175
San Pablo	258	14	Sacramento	25	76
Oakland	8	15	Auburn	1,500	108
Grizzly Peak	1,760	11	Williams	86	110
Livermore	475	42	Corning	285	172
Tracy	64	60	Red Bluff	330	192
Los Banos	100	116	Redding	722	222
Atwater	153	110			

subject to appreciable change it at once becomes the only reliable index of composition. Examining the humidity records from the airport stations in the interior valley, we find that on August 13 the lowest dew point recorded at the four hourly periods varies from 35° F. at Redding in the northern end of the Sacramento Valley to 46° F. at Bakersfield in the extreme southern end of the San Joaquin Valley. Grizzly Peak recorded a dew point of 33° F. at 8 a.m. and by 5 p.m. it had dropped to 32° F. on August 13; and the lowest dew points in the bay region were 51° F. at Oakland and San Francisco, and 50° F. at San Francisco airport.

However, dew point is a measure of the absolute humidity, but takes no account of the differences of density of the air, which may be considerable. The specific humidity, which is defined as the ratio of the mass of water vapor to the total mass of moist but unsaturated air, per unit volume, takes into account the density differences of the various air masses. The specific humidity was computed for a number of stations. Data from the regular city offices of the Weather Bureau at Red Bluff, Sacramento, San Francisco, and Fresno were used. In all other cases the data are those secured from airport stations. The specific humidities computed are set forth in table 1.

TABLE 1.—*Minimum specific humidity values*

Station	Time of occurrence and date	Parts per thousand
Bay region stations:		
San Francisco	5 a.m. 13	7.88
Oakland airport	6 a.m. 13	8.01
San Francisco airport	5 a.m. 14	7.02
Santa Clara Valley:		
Sunnyvale Naval Air Station	8 a.m. 13	9.40
Mount Hamilton	6 a.m. 13	4.18
Eastward across the valley:		
Sacramento	5 a.m. 14	6.27
Auburn	9 p.m. 12	6.11
Blue Canyon	9 p.m. 12	5.74
Reno	1 p.m. 12	4.23
Northward in the valley:		
Williams	5 a.m. 14	5.40
Red Bluff	5 a.m. 14	5.45
Redding	1 p.m. 13	4.38
Southward in the valley:		
Atwater	1 a.m. 13	5.63
Fresno	5 a.m. 13	4.48
Bakersfield	1 a.m. 13	6.64
Sandberg	9 p.m. 12	4.27

Bakersfield appears to be discordant, but in all probability the dry air had not penetrated to the southern extremity of San Joaquin Valley before there was a change in air mass movement. Sandberg shows a low specific humidity, but it is situated on the north slope of the Tehachapi Mountains at an altitude above 4,000 feet.

A most cursory examination of the table shows that the specific humidity is highest in the Bay Region and adjoining Santa Clara Valley, that it diminishes as we progress eastward into the interior valley with a further decrease as the Sierra are crossed. A regular decrease is noted northward and southward in the Sacramento and San Joaquin Valleys.

Insufficient data are available to compute the specific humidity for Grizzly Peak, but the specific humidity at Mount Hamilton (4,200 feet) was found to be lower than that at any other station.

The high specific humidity and the low temperature in the Bay Region, the high temperature on Grizzly Peak and the low specific humidity on Mount Hamilton, give ample evidence that two separate air masses are involved and a digression to deal with this situation seems apropos.

Four observations are taken daily on Grizzly Peak. At 8 a.m. of the 13th the temperature was 88° F., it was calm, clear, and the dew point was 33° F. By noon the wind was north 2 miles per hour and the temperature had risen to 100° F. By 3 p.m. it was 102° F., and the wind had gone into the west 3 miles per hour. The temperature rose until shortly after 3 p.m., when a maximum of 104° F. was reached. By the time of the 5 p.m. observation the temperature had dropped to 94° F. the dew point was 32° F., and the wind was still from the west at 5 miles per hour. No pressure readings were taken and the specific humidity cannot be computed, but the dew point and temperature data show indubitably that the air can be placed in the category of an air mass whose chief characteristic is its dryness. The depth of this mass of dry air is not known, but as will be shown later, it extended from a few hundred feet above the surface to an altitude greater than that of Mount Hamilton, 4,200 feet.

During the same interval of time the weather near the surface of the bay as indicated by records from Oakland Airport, the San Francisco office, and San Francisco Airport, was of a decidedly different nature. At 8 a.m., at Oakland a heavy stratus overcast was showing an occassional break and the ceiling had increased to 800 feet from 400 feet recorded 1 hour before. The temperature was 56° F. and the wind had just gone into the west from the north and northeast. By 9 a.m., the stratus cloudiness covered about four tenths of the sky and by 9:25 a.m., not a trace was to be seen. All day long the wind was between west-southwest and west-northwest with a speed of about 8 miles per hour. The dew point was 53° F. at 8 a.m., and rose to 58° F. at noon, but decreased to 54° F. by 3 p.m. The maximum temperature of 82° F. occurred at 3 p.m. Data obtained from the meteorograph at San Francisco and the three daily observations agree closely with that from Oakland except that the temperatures were somewhat lower and the wind was stronger at San Francisco. San Francisco Airport data were in agreement with San Francisco and Oakland.

The conditions above discussed are shown graphically in figure 1, which is a copy of the Grizzly Peak hygrothermograph trace from August 12–16, 1933. It will be seen that the humidity remained low throughout the 12th and 13th and the diurnal fluctuation was slight. The temperature mounted higher each day until the maximum of 104° F. was reached on the 13th. The range in temperature was small. On the 11th, 12th, and 13th, the minima were higher than the maxima for the same dates at Berkeley and San Francisco.

For purposes of comparison table 2, showing the maximum and minimum temperatures, and the 5 a.m., noon, and 5 p.m., relative humidities, for San Francisco and Grizzly Peak Lookout, follows:

TABLE 2

	San Francisco					Grizzly Peak Lookout				
	Relative humidity			Temperature		Relative humidity			Temperature	
	5 a.m.	Noon	5 p.m.	Maximum	Minimum	5 a.m.	Noon	5 p.m.	Maximum	Minimum
Aug. 11	96	58	59	68	51	31	30	21	98	75
Aug. 12	96	75	76	63	51	18	16	27	92	80
Aug. 13	100	60	71	71	50	20	24	18	104	74
Aug. 14	81	77	83	63	53	20	62	72	76	66
Aug. 15	96	78	74	66	54	99	76	94	70	51

The elevation of the instruments at San Francisco is 238 feet (a.m.s.l.), and 11 miles east, air line, are located the instruments at Grizzly Peak Lookout, 1,760 feet (a.m.s.l.).

Humidity conditions on Mount Hamilton are graphically depicted by figure 2, a copy of the hygrograph trace from there. It shows the same characteristics as the Grizzly Peak trace. The humidity was very low during the first days shown with little diurnal change.

The data given above indicate clearly that the lower air moving over San Francisco and the Bay Region is of a decidedly different composition from that at Grizzly Peak and Mount Hamilton. The temperature, dewpoint, and direction of the wind permit no mistake in determining the source of this air mass. It is marine air moving from the ocean through the Golden Gate and northeastward into the valley in response to a pressure gradient between the ocean and the interior due to the high temperature in the enclosed valleys. No definite data are available, but in all probability the marine air was invading smaller coastal valleys including Santa Clara, Salinas, and Petaluma.

How deep was this layer? No definite measurement was obtained, but an approximation was made as follows: The writer drove up to Grizzly Peak over a rather circuitous road with easy grades and arrived at the top about the time of the maximum temperature. The descent was over a much steeper road, but the change from the cool marine air to the hot dry air and vice versa was most pronounced. There was no gradual transition, but an abrupt change from one layer to the other. This surface of discontinuity was estimated to be 600 feet above the sea by comparison with certain landmarks on the ascent and descent. Determination of the eastern boundary was not easy or certain. The air made its way northeast across the bay and into the valley, where it was mixed with the drier air and its identity was lost. The marine air advanced as a wedge, presumably, and the thin, forward part soon reached a place in the valley where the warming through insolation was just offset by the change brought about by the importation of cold air. From that point eastward there would be no lowering of the temperature as the marine air moved inland. However, there was a noticeable difference in the specific humidity of stations lying directly across the valley and in line with the opening through which the air passed and those on either side. The specific humidity at Sacramento and Auburn was somewhat lower than at Oakland and San Francisco, but somewhat higher than at Atwater and Williams, the next stations to the south and north, respectively.

The above discussion of surface weather of the San Francisco Bay area and contiguous territory and at the elevated stations, Grizzly Peak and Mount Hamilton, together with the data depicted in figures 1 and 2, indicates that there is a marked inversion in temperature with ascent. Confirmation of this statement was sought in aerographic data from Sunnyvale Naval Air Station. No flight was made on Sunday, August 13, but temperature and dewpoint data are available from a flight that started at 9 a.m. on the 14th. It is reproduced as part 1 of figure 3. There is a marked temperature inversion beginning at 1,200 feet. The separation of the dewpoint and temperature curves with increase in altitude also indicates that the higher layers of air were dry. The temperature inversion was most marked on this date.

Summarizing, it may be said that two totally different air masses are involved. One is dry and warm and has overspread California north of the Tehachapi Mountains. This warm air is being underrun by a thin layer of cold, moist air that makes its way inland through the Golden Gate and then northeastward where it is mixed with the drier air and warmed through insolation, and its identity lost. A slight increase in the specific humidity is noted at a few of the inland stations. In the Bay region the surface of discontinuity is pronounced.

Despite the influx of the shallow layer of marine air the maximum temperatures around San Francisco Bay and in the Santa Clara Valley were higher than those of the preceding day. The rise was 8° F. at San Francisco, 10° F. at Oakland and Berkeley, 11° F. at San Pablo, 9° F. at San Jose and Sunnyvale Naval Air Station. In the coastal valleys and the large interior valley the changes were inconsequential, amounting to only a degree or two and positive for the most part.

The characteristic stratus cloudiness of the Bay region did not form on this night. Why not?

First of all let us consider the physical processes involved in the formation of these clouds. In his paper "The Summer Nighttime Clouds of the Santa Clara Valley of California", E. H. Bowie states the theory of formation of these stratus clouds.[1] The following is quoted from his paper:

> The actual origin of these clouds appears to be the excess of emitted over absorbed radiation. It is known that air rich in water vapor is selectively highly absorptive of terrestrial or long-wave-length radiation; and being a good absorber it also is a good radiator in the same spectral region, in fact as good, nearly, as a black body. Conversely, dry, clear air is diathermanous to terrestrial or long-wave-length radiation and therefore in that region a nonradiator, and its temperature subject to change only by work done by it or upon it. Hence at night the stratum of marine air rich in water vapor cools radiationally while the stratum of dry air above it remains at a constant temperature or, at most, loses its heat very slowly. The truth of this statement is proven by the marked cooling of the earth's surface at night, when the overlying air is still, while the air itself is cooling but little, except near the ground, and there by contact with the cold surface.
>
> From the foregoing, the conclusion is reached that the formation of stratus clouds over the Santa Clara Valley during the summer is to be regarded as a radiative phenomenon, occurring when the valley is flooded by air of marine origin, rich in water vapor, and when it in turn is overlain by air of quite low humidity. When this situation exists the excess of outgoing over incoming radiation is at its maximum at the upper surface of the bay of marine air, and sometime during the night the cooling thus caused reaches the dew point, condensation starts and cloud forms. It does not necessarily follow that the dew point is reached first at the upper surface of the humid air; it may be at some intermediate altitude between this surface and the bottom. When the dew point is reached at the upper surface first, the growth of the cloud is downward; whereas when it is reached first at an intermediate altitude the growth of the cloud is both upward and downward. Ultimately the cooling throughout the marine air, from a maximum at its upper surface downward to a minimum at its bottom, may result in the lapse rate exceeding the adiabatic, when there will follow convection and turbulence that would cause a pilot passing through or under the cloud to experience bumpiness. This convective turbulence increases the rapidity of cloud formation. The descending currents, the counterparts of the ascending currents in the convective process, are not heated at the adiabatic rate for dry air, for in them there is a loss of heat by evaporation, the equivalent of that gained by condensation in the ascending currents. As the cooling proceeds the thickness of the cloud increases and at times the entire mass of marine air is filled with cloud from top to bottom.

The layer of marine air was very thin. As stated before, the writer estimated the depth to be 600 feet after driving up through it to the Grizzly Peak Lookout. However, Grizzly Peak is not an isolated peak but a promontory of the Berkeley Hills, which are nearly of uniform height and extend north and south along the east side of the bay. Because of the extreme difference in temperature between the top of the ridge, as shown by Grizzly Peak temperatures, and the base, as indicated by the temperature at Berkeley, and because of the westerly winds across the bay, the marine air may have been higher up on the slope than in the free air to the westward. However, it extended over 200 feet in depth, because the

[1] MONTHLY WEATHER REVIEW, February 1933, vol. 61, pp. 40-41.

thermometer at the San Francisco office is 208 feet above the ground and was within the layer of marine air. In any event the layer was shallow and overlain by a layer of air with a much higher temperature and lower humidity. One of the conditions necessary for cloud formation is that the air must cool radiationally to the dew point temperature from the maximum temperature of the day, providing there is no air mass importation. If there is an invasion of marine air early in the day the temperature will drop perceptibly, as much as 10° to 15° in a few hours. In such a case the temperature, when cooling begins, or temperature when the incoming and outgoing radiation are equal, will be at some time late in the day. This temperature will be lower than the maximum temperature which most often occurs just prior to the arrival of the marine air. However, on this date the starting point (the maximum temperature) was high enough so that the cooling during the night was not sufficient to reduce the temperature to the dew point. Moreover, the cooling of such a thin layer would be more or less uniform throughout because of wind and turbulence and not greatest at the top of the layer.

Another factor that precludes the formation of stratus clouds on the first night after the air from the ocean begins its invasion is the moisture content of the incoming air. During the regime of the "land breeze" the easterly winds may become pronounced and considerable continental air may be carried out to sea. A reversal of the wind serves to return this air. The first air to invade the land is a transitional air mass, a mixture of marine and continental air whose moisture content is lower than that of the marine air which follows it inland. This air is too dry to permit the formation of stratus clouds.

The hygro-thermograph trace for Grizzly Peak Lookout, figure 1, shows an abrupt fall in temperature coincident with a rise in the relative humidity at 7 a.m. of the 14th. Grizzly Peak is located due east of the Golden Gate and across San Francisco Bay. The first invasion of the marine air in all probability advanced as a narrow "spear head" with little lateral spreading and was in evidence only in the region directly east of the Golden Gate. On this date at San Francisco the temperature was higher, hour for hour, when compared with the day before, until 10 a.m., when the wind increased in speed to 12 miles per hour from 4 miles per hour and the sea breeze began its extension into the interior. At this time the temperature rise ceased for the day. By noon this marine air had reached Oakland and the wind shifted from north to northwest and the speed increased to 18 miles per hour. This wind continued throughout the day, and it will be noted that the speed was more than double that of the day before. The airways station at San Pablo noted the arrival of the cold air at 11 a.m. At Livermore the wind shifted from southwest to west-northwest then into the west at 22 miles per hour shortly before 2 p.m., when the cold air arrived. It continued eastward through Altamont Pass and reached Tracy about 3 p.m., when the wind change was from light northwest to fresh westerly. Winds in the San Joaquin Valley were northwesterly all day but increased considerably in speed as the marine air arrived. The time of arrival at Los Banos was 5 p.m., and at Atwater 8 p.m. of the 14th. It did not reach Fresno until 10 a.m. of the 15th.

In the Sacramento Valley we find the same regular progression. The wind at Sacramento had been very light northerly with frequent calms. Upon the arrival of the "sea breeze" at 4 p.m., the wind went into the southwest at 18 miles per hour. Moving in a wide arc the marine air reached Auburn at 8 p.m., when the wind shifted from west-southwest to south-southeast and increased in speed. As in the San Joaquin Valley, progress during the night was slow because of the reduced gradient occasioned by nocturnal cooling; but by 5 a.m. of the next morning the sea breeze had reached Williams, at 6 a.m. it passed Corning, and at 7 a.m. it passed Red Bluff, and arrived at Redding about 8 a.m. As at Auburn the wind was from the southeast when the air of marine origin arrived, seeming to indicate that the air moved as a distinct current in an east-northeasterly direction until diverted by the mountains, then flowed north-northwestward.

On the frontispiece the arrows show only the two main paths of the marine air. No attempt was made to determine the course followed by the air in entering the smaller valleys. There may have been some diversions from the main paths within the interior valley. The path of the marine air is also indicated in figure 4 by the hourly positions of the advancing front. Because of the small scale of the map it was not possible to show the positions of the front between the Golden Gate and Grizzly Peak Lookout in the early morning. The first position shown is at 10 a.m., the time the marine air invasion became pronounced. By the time the front had reached Fresno the depth of the air off the coast had increased to a height greater than that of the low coastal mountains northwest of Bakersfiled, permitting ocean air to enter the upper San Joaquin Valley. With the marine air entering from this region and also flowing up the valley, it was difficult to locate the front. Hence no fronts are drawn south of Fresno.

Later in the day as the valley became filled with the marine air, the winds in the upper part of the Sacramento Valley gradually shifted into the south and finally into the southwest.

The path and rate of advance of the marine air in the interior valley were determined from hourly values of temperature, pressure, and wind from airways stations for the most part. Temperature records from cooperative stations and the daily meteorological records from San Francisco and Red Bluff were also used. Cooperative station records only were available in the coastal valleys.

At this point it seems appropriate to again refer to figures 1 and 2, this time to the second part. The temperature trace for Grizzly Peak shows that the temperature began a marked and steady decrease upon the arrival of the marine air on the 14th. Coincident with this temperature drop was an equally rapid rise in the relative humidity. During the following 24 hours there were only minor fluctuations in the humidity trace.

An examination of the hygrograph trace for Mount Hamilton shows that the marine air did not arrive there until late on the 14th. The rise in humidity was rapid, but the saturation point was not reached during the period shown.

An interesting point to consider is the rate at which the marine air increased in depth. It was noted at Grizzly Peak Lookout (1,760 feet, a.m.s.l.) at 7 a.m., and the time of its arrival at Mount Hamilton (4,200 feet a.m.s.l.) was determined as 6 p.m. This is an increase in vertical depth of 2,440 feet in 11 hours, or at the rate of 222 feet per hour.

The aerographic flights from Sunnyvale for August 15 and 16 are shown as parts 2 and 3 of figure 3. Comparing them with part 1, it can be seen that the temperature inversion is much less pronounced, that the dew-point curve is roughly parallel to the temperature curve, and that the dewpoint is higher at the top level by 18° F., on the 16th than on the 14th.

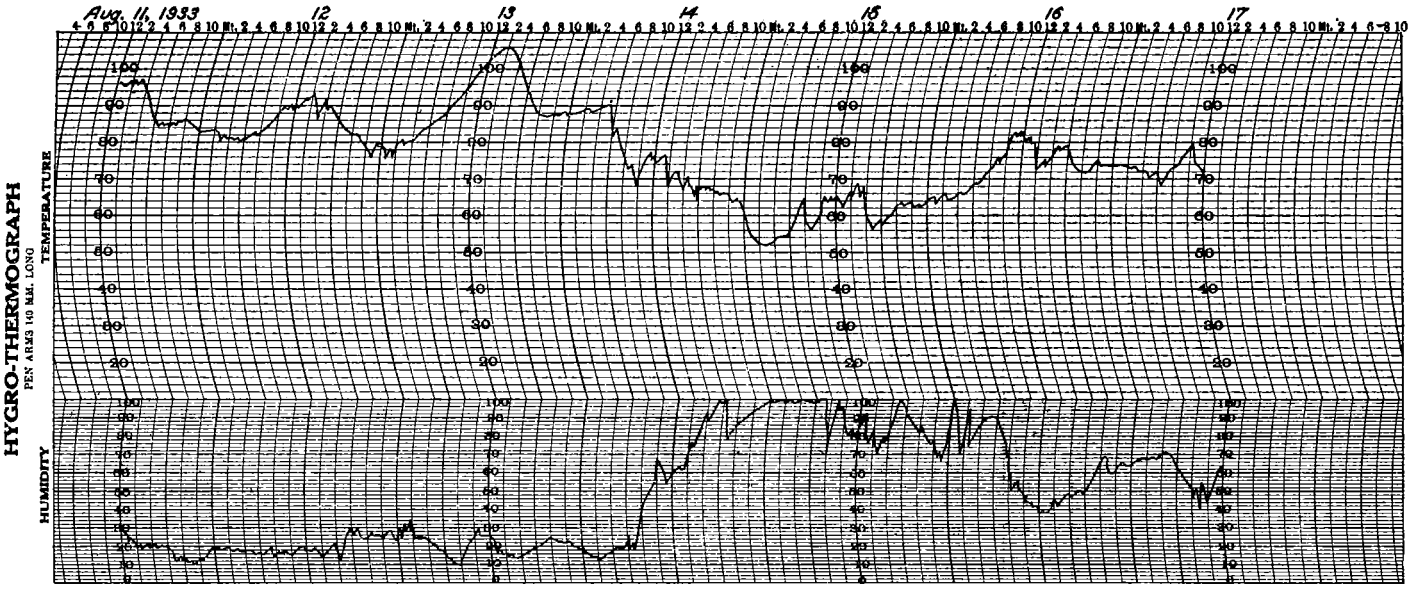

FIGURE 1.—Hygro-thermograph trace from Grizzly Peak Lookout (1,760 feet), August 12–17, 1933. Observations taken at 8 a.m., noon, 3 p.m., and 5 p.m. Figures indicate difference between observation and trace values.

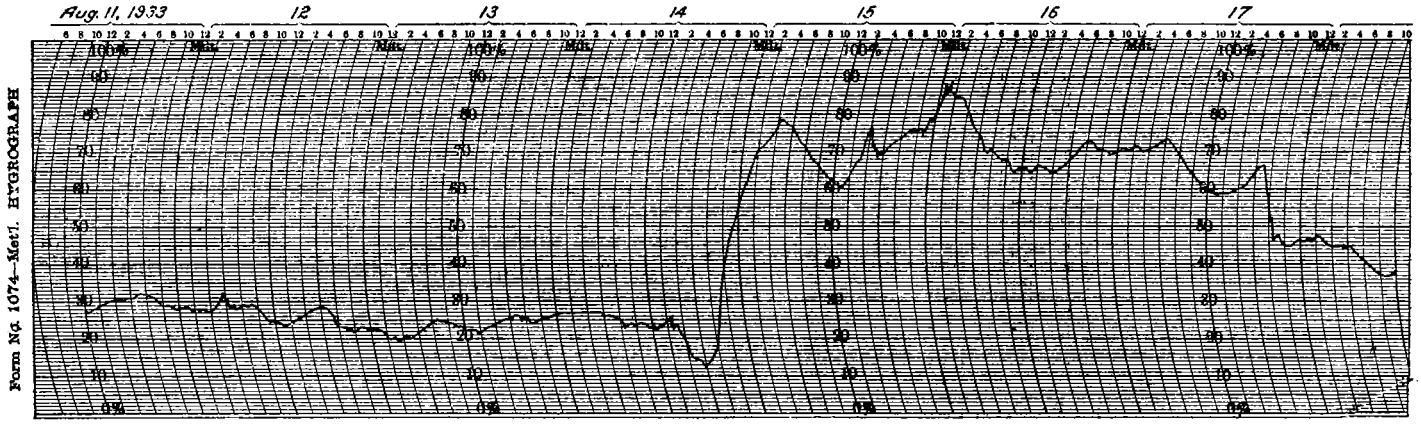

FIGURE 2.—Hygrograph trace from Mount Hamilton (4,200 feet), August 12–17, 1933. Observations taken at 5:45 a.m. and 4:45 p.m. Figures indicate difference between observation and trace values.

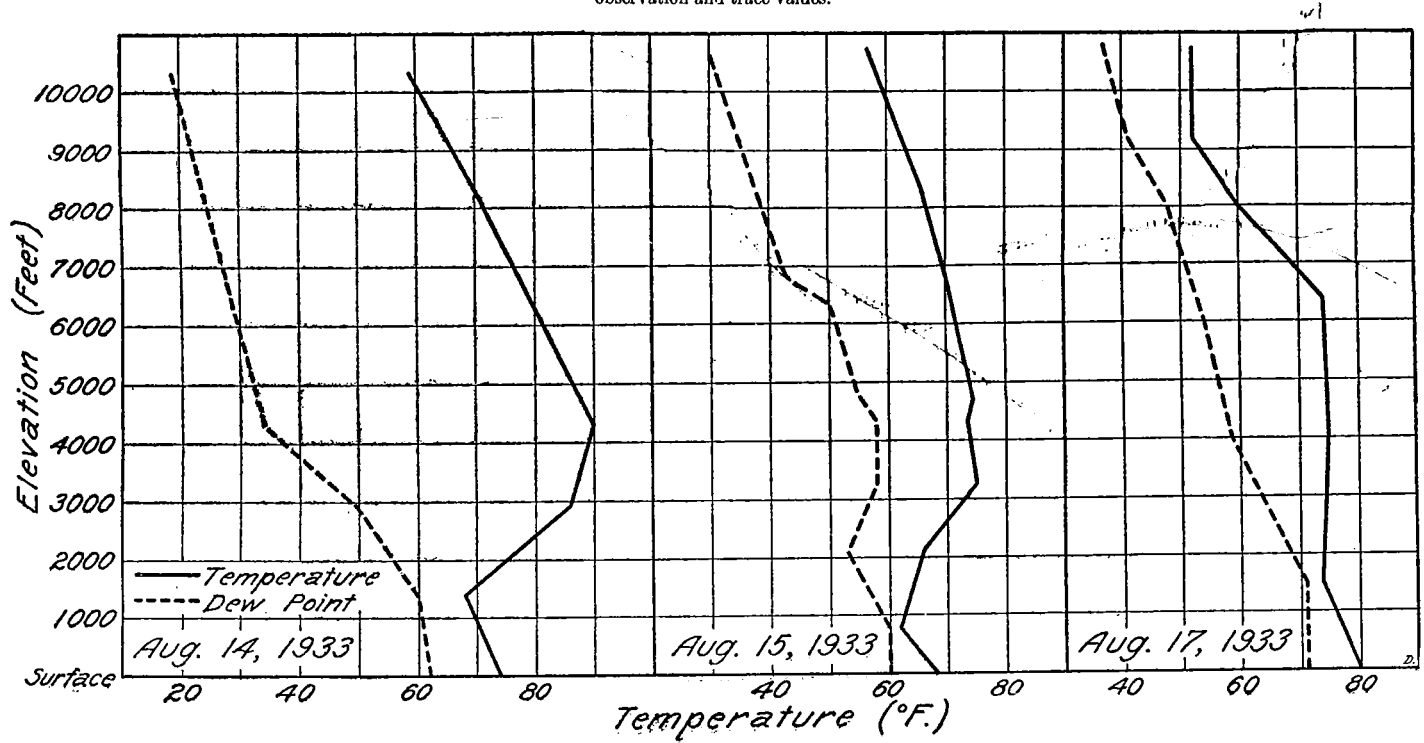

FIGURE 3.—Data from Sunnyvale Naval Air Station aerological flights. Starting time, 9 a.m.

The facts enumerated above show unmistakably that the marine air has reached a height of 10,000 feet, the top level of the flights, and has entirely displaced the dry air from the surface to that height.

The change in the maximum temperature from the 13th to 14th and from the 14th to 15th is shown in table 3.

TABLE 3.—*Maximum temperatures and changes*

Station	Aug. 13	Aug. 14	Aug. 13–14 change	Aug. 15	Aug. 14–15 change
	°F.	°F.	°F.	°F.	°F.
San Francisco Bay region:					
San Francisco	71	63	−8	66	3
Crissy Field	60	59	−1	62	3
San Pablo	75	69	−6	69	0
Crockett	81	76	−5	71	−5
Grizzly Peak Lookout	104	76	−28	70	−6
Berkeley	74	64	−10	64	0
Oakland	83	76	−7	70	−6
Oakland Municipal Airport	82	70	−12	69	−1
San Francisco Airport	72	73	1	76	3
Santa Clara Valley:					
Santa Clara	92	91	−1	83	−8
Los Gatos	100	90	−10	91	1
Sunnyvale Naval Air Station	86	83	−3	76	−7
San Jose	94	91	−3	81	−10
Mount Hamilton	98	100	2	84	−16
Sacramento Valley:					
Vacaville	111	111	0	95	−16
Davis	111	109	−2	96	−15
Woodland	110	113	3	99	−14
Corning	113	116	3	101	−15
Sacramento	111	104	−7	89	−15
Rocklin	115	118	3	101	−17
Williams	114	117	3	98	−19
Colusa	112	114	2	100	−14
Marysville	112	115	3	99	−16
Willows	110	113	3	98	−15
Chico	110	115	5	106	−9
Orland	114	117	3	100	−17
Red Bluff	111	114	3	101	−13
Redding	110	113	3	99	−14
San Joaquin Valley:					
Antioch	103	103	0	88	−15
Lodi	108	101	−7	89	−12
Stockton	106	101	−5	89	−12
Los Banos	109	105	−4	98	−7
Los Banos Airways station	108	110	2	92	−18
Tracy	108	106	2	90	−16
Modesto	105	103	−2	90	−13
Atwater	108	109	1	94	−15
Le Grande	110	108	−2	98	−10
Fresno	112	112	0	98	−14
Fresno Airport	112	112	0	100	−12
Hanford	115	115	0	98	−17
Waco	113	112	−1	101	−11
Bakersfield	114	117	3	104	−13
Bakersfield Airport	116	117	3	103	−14
Livermore Valley:					
Livermore	110	99	−11	90	−9
Livermore Airport	107	95	−12	87	−8
Salinas Valley:					
Salinas	78	72	−6	79	7
Watsonville	72	74	2	65	−9
King City	96	99	3	85	−14
San Benito Valley:					
Hollister	97	82	−15	86	4
North coastal valleys:					
Petaluma	88	89	1	84	−5
Santa Rosa	87	97	10	85	−12
Ukiah	111	107	−4	96	−11
Calistoga	109	98	−11	101	3
Healdsburg	102	89	−13	82	−7
Cloverdale	108	98	−10	89	−9
Foothill and lower mountain stations:					
Auburn	107	110	3	95	−15
Auburn Airport	106	108	2	92	−16
Blue Canyon	97	99	2	86	−13
Blue Canyon Airport	93	94	1	81	−13
Placerville	110	114	4	96	−18
Tejon	104	110	6	97	−13
Sandberg	102	92	−10	83	−9
East slope Sierra:					
Soda Springs	87	87	0	88	1
Truckee	95	96	1	96	0
Reno, Nev	103	102	−1	102	0

Several features in the changes in temperature shown in the foregoing table deserve attention. The changes in the Bay Region are all small, except at Grizzly Peak. Crissy Field, the Army air field, is situated on the south side of the Golden Gate and was within the current of marine air on both days. San Francisco Airport is similarly situated. It is located on the west side of the bay and separated from the ocean by a narrow peninsula with low hills. There is a gap between the hills that averages less than 100 feet in height and does not rise more than 200 feet at the highest point. This offers easy access to oceanic air. The largest temperature change occurred at the Oakland Airport which is located on the east side of the bay and 10 miles east-southeast of the Golden Gate. In this location the influence of the marine air would be at a minimum on the 13th.

In the Santa Clara Valley the change to lower temperature took place on 2 days. This leads to the deduction that the air of marine origin did not come directly over the hills to the west of the valley, but followed a rather circuitous path, probably, through the Golden Gate and the gap to the south, over the lower coastal hills south of the Gate, and then southward over San Francisco Bay. Further evidence of such a course is indicated by the wind at Sunnyvale which was north or north-northwest throughout the 13th, 14th, and 15th.

The mass of marine air entered the Sacramento Valley on the afternoon of the 14th, but after the maximum temperature had occurred; hence the large maximum temperature changes were not recorded until the 15th. However, there were a few negative changes in the region near the confluence of the two rivers.

It was soon after noon when the cold air reached the Livermore Valley, and large changes are noted there on both days. The rapidity with which the marine air reached Livermore leads to the conjecture that it may be through this valley that most of the air entering the San Joaquin Valley passes, rather than northeastward from the Golden Gate through San Pablo and Suisun bays and then southeast into the valley. Supporting evidence is supplied by the fact that the stratus cloudiness so typical of the Bay Region and coastal sections often penetrates far enough eastward to cover the Livermore Valley. The direction of the wind is a deciding factor, and Tracy wind reports are predominantly westerly.

Temperatures did not change materially on the east slope of the Sierra Nevada. The reason is twofold. The air from the plateau was forced to rise in passing over the Sierra Nevada, and the dynamic heating so pronounced on the west slope and in the interior valley of California was absent on the east slope. There the winds were ascending and the maximum temperatures on the 13th and 14th were about the same as they were in the valley on the 15th, after the marine air had entered. Moreover, as the wind reversed and the marine air crossed the Sierra there was dynamic heating as it descended the east slope. This warming offsets any lowering of the temperature that was occasioned by the importation of marine air from the Pacific.

The Salinas Valley temperatures exhibit the same characteristics as those in the Bay Region because this valley offers the same easy passage to the oceanic air.

As the marine air made its way into the interior, the specific humidity rose steadily, and maximum values were reached at most stations late on the 15th; but a few in the extremities of the valleys did not attain maximum values until the morning of the 16th. As was to be expected, the dewpoint rose at all stations. The maximum specific humidity values are set forth in table 4, which follows:

TABLE 4.—*Maximum specific humidity values*

Station	Time of occurrence	Date	Parts per thousand
Bay Region:			
San Francisco	5 a.m.	15	9.75
Oakland Airport	Noon	16	11.99
San Francisco Airport	9 a.m.	16	11.17
Santa Clara Valley:			
Sunnyvale Naval Air Station	Noon	16	12.86
Mount Hamilton	1 a.m.	16	12.50
Eastward across the valley:			
Sacramento	5 p.m.	15	11.21
Auburn	1 p.m.	16	12.17
Blue Canyon	1 p.m.	16	16.58
Reno	9 a.m.	16	11.38
Northward in valley:			
Williams	5 p.m.	15	11.65
Red Bluff	5 a.m.	16	10.92
Redding	10 a.m.	16	11.47
Southward in valley:			
Atwater	1 p.m.	16	13.90
Fresno	Noon	16	11.70
Bakersfield	9 a.m.	16	12.63
Sandberg	1 a.m.	16	13.10

It will be noted that there is little difference in the specific humidity at any of the stations, including Mount Hamilton. This leaves no doubt as to the identity of the air mass involved. Blue Canyon specific humidity appears to be too high, but a thunderstorm occurred there on the 16th and the light rain which fell may have been responsible for the high value.

The weather map of 8 a.m. of the 14th shows that the trough from the southwest low in working northward has severed the oceanic and plateau highs. Conditions in the interior valley were still stagnant and Red Bluff reported the highest August temperature of record, as Sacramento had done the preceding day. Wind movement at all levels in the free air was predominantly westerly by the morning of the 15th, indicating that the transition period was over and that the control had passed from the dry hot air to the humid marine air. The marine air by this time had increased greatly in depth and had become deeper than the altitude of the coastal mountains. The eastward moving mass of cool, moist air passed over the coast range, across the interior valley and over the Sierra Nevada. Its forward edge had all of the characteristics of a cold front. On the 16th thunderstorms occurred throughout the entire length of the Sierra as indicated by reports from the fire weather stations and airways stations in the mountains. Reno also reported a thunderstorm on this date. Following the passage of the cold front the pressure rose rapidly; and by the evening of the 16th the Pacific high again extended into the plateau, the "land breeze" was again predominant. A few days later it was again superseded by the air from the ocean and the conditions discussed above were repeated, but to a less degree. The inevitable stratus clouds formed in the Bay Region on the night of the 14th–15th. On this date the marine air was much deeper, and the maximum temperature somewhat lower than on the preceding day. The cooling necessary to reach the dew point, which was practically the same as on the previous day, would be much less. Cooling on this night would be most pronounced at the upper surface of the marine air, where radiation is most active. Six hundred feet was the height of the first few patches of cloud that formed at the Oakland Airport about 11 p.m. of the 14th. Ceiling light measurements made some time later gave the height as 700 feet. The ceiling decreased to 300 feet by 3 a.m. of the 15th. At San Francisco airport, on the west side of the bay, the clouds did not form until 5 a.m. of the 15th and their base was 800 feet high.

The inversion in temperature had almost disappeared by the 15th and the layer of marine air extended upward to an unknown height. The junction of the marine air and the dry air which it was displacing was at some height above 10,000 feet, the height of the Sunnyvale aerographic flight, part three, figure 3. At such an altitude and after 3 days of contact, the interface would be less marked than when the marine air first pushed inland. The dew point graph of the aerographic flight referred to above shows that the moisture content of the marine air steadily decreased with ascent. A reduction in water vapor would reduce the effective outgoing radiation at the top of the layer. Hence any clouds that formed would do so slowly and if at the surface of discontinuity or somewhat below, would be so high as to be outside of the category of *stratus*. A few high clouds were noted at Oakland Airport on this night but no summer stratus.

SOME RESULTS OF SOUNDING-BALLOON OBSERVATIONS DURING THE SECOND INTERNATIONAL POLAR YEAR, AUGUST 1932 TO AUGUST 1933, INCLUSIVE

By J. C. BALLARD

[Weather Bureau, Washington, D.C., March 1934]

Sounding-balloon observations were made in the United States on international days of the first and second orders [1] at Dallas, Tex., Omaha, Nebr., and Ellendale, N.Dak. In June 1933 this work was transferred from Ellendale to Pembina, N.Dak., due to the closing of the former station. Six observations per month, made in two series of three flights each, were made at all three stations. In each case the series was begun about noon and the other two flights made at approximately midnight (12 hours later) and 6 a.m. (18 hours later), respectively, 90th meridian time. The total number of observations was 234—by far the largest number of sounding-balloon observations ever made in this country during a similar period. Eighty-five percent of the meteorographs have been returned.

The distribution of the observations with respect to time and place makes it possible to study various annual and latitudinal variations which heretofore have been undetermined because of lack of adequate data. The relatively short interval of time between the flights in any series also makes it possible to study individual cases of the variations with time of the conditions attending weather changes.

As a whole, the data acquired during the Polar Year is, no doubt, the most reliable yet obtained in this country, largely because of a better understanding of the behavior of the pressure-recording mechanism. However, the temperatures recorded on the day flights probably are still in error owing to insolation effects. If these errors are large, they obviously render the data useless for studying short-range variations accompanying weather changes. As much of this effect as possible was removed from the present temperature records as follows:

On every day on which flights were available for noon and the following midnight, the temperature change from noon to midnight was found for each standard kilometric

[1] That is, the second Wednesday and Thursday and the fourth Wednesday and Thursday in each month, respectively.